A Presence-Based Control Strategy Solution for HVAC Systems

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***Abstract*-This paper presents an energy-saving control solution which has been developed for existing public buildings by designing an intelligent ICT-based service system for monitoring and controlling the environmental conditions. The proposed control strategy addresses the required infrastructure and implements the design to properly balance energy savings and comfort issues. In this work, a combination of occupancy detection and daylight harvesting is presented as input to the control algorithm. The implemented results presented here utilize the hardware and software on a pilot campus and achieve an average energy saving of 71% for three sample days during summer times. Simulation results are also presented for annual period and complete test case building.**

I. Introduction

The Heating, Ventilation and Air Conditioning (HVAC) control applications include products, systems and services that provide environmental conditions (temperature, moisture, CO_2, etc) for the inhabitant's comfort while maintaining the building efficiency to minimize the energy consumption and operation and maintenance costs. Different methods can be combined to save energy costs for HVAC in a range of 15% to 30% [1], [2]. The main HVAC control principles that save energy, are to supply heating and cooling from the most efficient source, to free energy sources such as solar radiation through windows in winter time and using a good control of blinds, as well as to run appliances and equipment only when needed [3]. HVAC unit activity should be scheduled for occupied times for ex. in the morning, warm-up can be started as late as possible, in order to achieve a desired indoor temperature during occupancy time, considering the residual space temperature, the outdoor temperature, and the equipment capacity (optimum start control). Also the equipment can be shut down some time before the end of the occupancy, depending on the internal and external load and space temperature (optimum stop control). The shutdown time will be calculated so that the space temperature does not drift out of the selected comfort zone before the end of the occupancy [4]. Heating can be started at night, if necessary to maintain the internal temperature between 10°C and 13°C to prevent freezing. Research on appropriate control strategies has been conducted as a part of the development of an energy management system implementation. An integrated system along with the middleware and application layers is developed to manage the energy consumption and CO_2 footprint in existing public buildings and spaces without significant construction works, by an intelligent ICT-based service. Special attention has been paid to historical buildings to avoid damage by extensive retrofitting.

Furthermore, since the project aims at controlling heating, cooling and lighting systems using temperature, luminance and occupancy sensors, new control rules have been designed and tested, through software simulations, in order to properly balance energy savings and comfort issues. The thermal inertia of buildings leads to a low responsiveness of the HVAC system, which requires an anticipation of possible future use of a room in order to meet comfort requirement within a reasonable time when occupancy is detected. The use also of new action modes, like the air speed control of the fan coils, the use of lighting sensors placed on the desk boards (better estimation of the actual illuminances), has allowed a better reliability, efficiency and energy savings.

The advance of sensing technologies, which can communicate exploiting both wireless and wired technologies, allows improvement in control and monitoring, more pervasive monitoring of energy consumption and environmental parameters to ensure the best possible comfort conditions with the most efficient use of energy.

During SEEMPubS project, it has been designed and implemented a service-oriented infrastructure for public space monitoring and its possible exploitation in order to enable a widespread usage of this technology and to make possible a complete and effective control. The resulting framework enables interoperability between heterogeneous networks and devices, characterized by various types of hardware components and interconnection technologies, providing also an easy and hardware-independent access to them. It has been used to make services and applications, again across heterogeneous devices, to develop an energy-aware platform. In order to implement monitoring polices foreseen in the SEEMPubS project, the utilization of sensor nodes was required. These nodes needed to be interfaced with the middleware infrastructure adopted in the project, called LinkSmart.

The system not only provides the software developers with a middleware interface to interact with different sensor nodes independent of the hardware and communication standards, but it also allows using control strategies for energy savings to balance energy savings and comfort. This paper presents the main parts of the developed system and explains the applied control strategy result for a case study.

II. Software Architecture

In typical energy management system, users prefer to access the environmental parameters measured by the sensor nodes

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via a hardware-independent interface at a high level. The software infrastructure presented here, exploits a web-service-oriented approach in order to manage heterogeneous devices based on different protocols, enabling interoperability and providing hardware abstraction. The starting point for this work was the LinkSmart middleware [5]. It provides features for enabling a peer-to-peer (P2P) communication; based on events, directly connect all the devices inside the LinkSmart network, no matter if they are behind a firewall or the Network Address Translator. The event-based communication exploits the publish/subscribe approach for LinkSmart web services, which allows the development of loosely coupled event-based applications. As shown in Figure 1, the proposed solution has a three-layered software infrastructure with i) the Integration Layer, ii) the Middleware Layer and iii) the Application Layer. The LinkSmart middleware provides a remote connection utilizing a software interface called PC-Gateway (GW) [6].

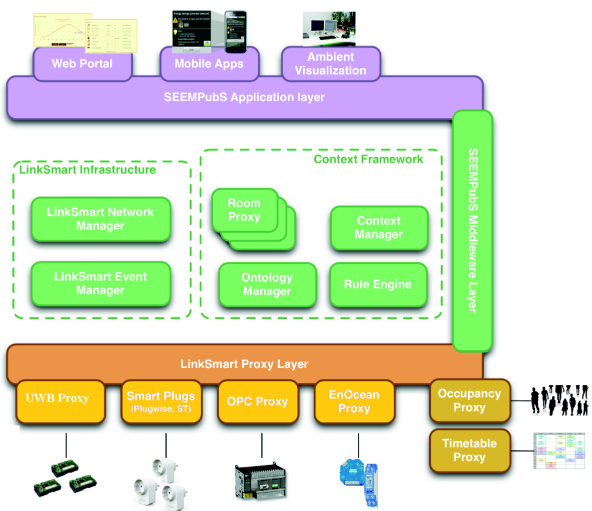

Fig.1. Detailed architecture of the energy management system

The Integration Layer, which is the lowest layer, enables the interoperability of heterogeneous devices with a dedicated interface called proxy. It acts as a bridge between the LinkSmart network and the underlying technology, so a specific proxy needs to be developed for each technology. This modular approach, based on proxies, provides to the whole infrastructure flexibility with respect to new emerging standards and technologies. In this system, the heterogeneity and interoperability issues have been proven by applying IEEE 802.15.4, ZigBee, UWB and EnOcean wireless sensor nodes, simultaneously [7]. The Middleware Layer enables the P2P communication and provides the event-based approach. In addition, a specific component has been developed to give additional information about the building and its occupancy, which are useful to develop rules and control strategies to minimize the energy waste. The Application Layer represents the higher layer. It provides a set of API's for developing distributed event-based applications to manage the building and to provide feedback to end-users. In the implemented system three applications have been developed: i) a HVAC control system, ii) a smartphone application and iii) a web portal [6].

III. ENERGY CONSERVATION STRATEGIES FOR HVAC

The economic advantage of the intermittent use of heating systems in intermittently-occupied buildings (e.g. schools, office buildings) is no longer in doubt. Nevertheless, the optimal energy consumption requires that the heating restart time is defined with great precision. In many cases, to avoid risks, the lowering of the temperature during non-occupancy periods is limited, which leads to a reduction in the energy savings. An intermittent heating controller allows the internal temperature to be lowered during non-occupancy periods, while maintaining the desired temperature during occupancy periods, when these periods are clearly defined. This work goes further by including occupancy detection [8]. A preset schedule is defined that allows turning off the heating when the room is unoccupied, unless a presence is detected. However, the user can always override the system by changing the set-point temperature of the fan coils with an individual switcher. In fact, a lot of classrooms or offices are not used during entire time of the scheduled period. If no presence is detected, the heating is stopped after a small delay. The strategies we have tested are divided in two parts depending on the information we have for the room: for rooms in which a presence prediction is impossible (for example a teacher office), we use a scenario which permits to heat the room the whole day at a base level to ensure an internal comfort when the user comes. Nevertheless, this strategy allows energy savings if there is no presence during a day because, in this case, the office will be heated at a lower set-point temperature. The other case is a thermal strategy for the rooms where we can predict the presence by the utilization of a schedule (for example a meeting room, a classroom or an office with regular occupation). The possibility of knowing the user presence or absence in the room allows to anticipate the start of heating for sufficient user comfort when people arrive, and also to anticipate the heating stop to perform energy savings if the room is empty after the occupation. These strategies also rely on a better management of the fan coil speed by automating the setting: Longer the indoor temperature approaches the set-point temperature; the more the blowing velocity is reduced. In this manner, the power of the fan coil varies with the speed and is better adapted to the energy needs of the room in summer and in winter. The proposed HVAC control strategy is shown in Figure 2. For an experimental case study, the proposed system has been implemented in an historical building with a sensors and actuators network on a site with a couple of rooms. Every room has an area of about 62.40 m^2, a frescoed domed roof with a maximum height of 7.25 m and a minimum height of 5.70 m, and a capacity of three working desks. During the test period of three days in summer, an average energy saving of 71% has been achieved [6], [9]. Table I shows the result.

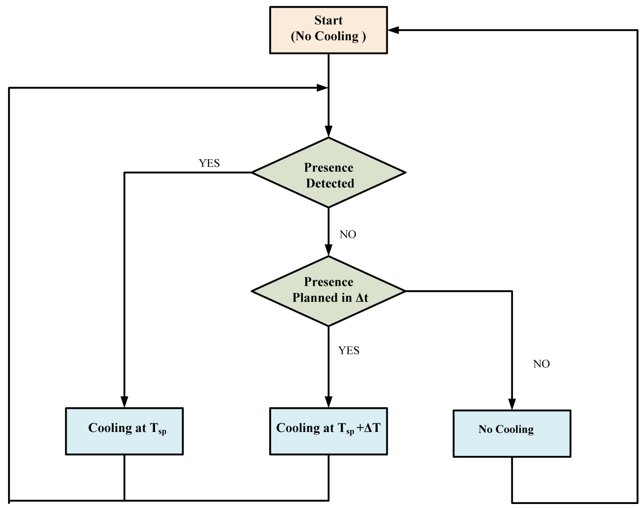

Fig. 2. HVAC control strategy (for example: Tsp=26°C and ΔT=3°C)

TABLE I. COOLING SAVING ON PRIVATE OFFICES IN SUMMER TIMES

Day	Consumption of ref. room (KWh)	Consumption of test room (KWh)	Savings (%)
Coolest	0.94	0.17	82%
Normal	2.38	1.14	52%
Hottest	7.53	1.60	79%

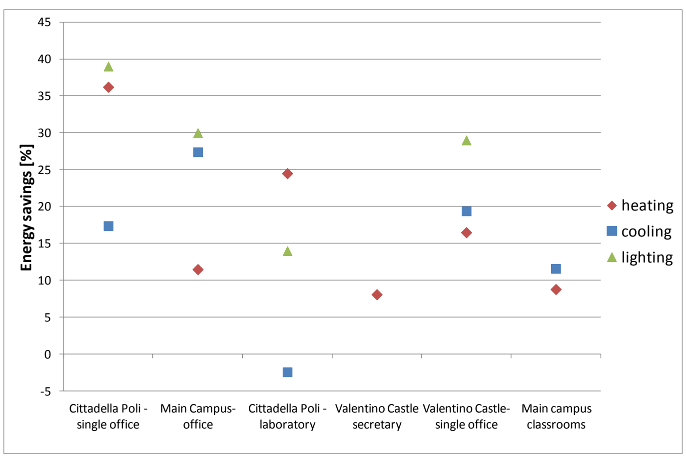

Fig. 3. Energy savings (in %) obtained for heating, cooling and lighting

Figure 3 presents the percentage savings for heating, cooling and lighting obtained with the new control strategies with respect to traditional (manual) controls (savings for test rooms with respect to reference rooms). The results for a complete year have been determined by simulations. These simulations have been validated with the monitored data during different periods of running of the controller. The results are presented for the six pairs of rooms of the Politecnico di Torino that have been taken as case studies [10].

IV. CONCLUSION

In this paper an implementation has been presented of an intelligent ICT-based service system for monitoring and controlling the environmental conditions in a real existing building. A self-adaptive system for climate and users has been tested and has shown its importance in terms of energy savings. This system design is flexible and can be applied to other types of buildings and more climates, without a need for a diagnosis of the building or heating system. Moreover, the control strategies have been established with the aim to maintain a good thermal comfort, especially at the beginning of the work starting time. For an experimental case study, an average energy saving of 71% has been achieved during the test period of three days in summer. For the annual period and for the overall case test buildings, simulation results have been also presented: for these cases, the energy savings can reach up to 40% for lighting, 35% for heating and 30% for cooling.

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